Goals and Objectives

- **Base Propulsion Technology Goals**
  - Focus on the objectives of reducing operations, manufacturing, and development costs and enhancing performance to contribute to the achievement of the following goals by 2025:
    - Reduce Costs By 100X ($100 per Pound)
    - Improve Safety By 10,000X

- **Code R Goal 9 (Earth-To-Orbit)**
  - Achieve within 15 years
    - Increase safety by two orders of magnitude
    - Reduce the cost to NASA transportation of placing payloads in orbit by one order of magnitude
  - Within 25 years,
    - Increase safety by four orders of magnitude
    - Reduce the cost of placing payloads in orbit by two orders of magnitude

Technical Challenges

- Improved propulsion performance to specific impulse (Isp) > 500 sec using combined cycle air-breathing rocket propulsion
- Increased all propulsion system thrust-to-weight ratio through the use of metal matrix composites, ceramics, and other advanced materials
- Increased propulsion life cycle capability to 500 missions through advanced design techniques and materials
- Decrease development cost through advanced design techniques and robust testing

Stakeholders

- **Marshall Space Flight Center (MSFC)**
  - For the Base Propulsion Technology Project, MSFC is responsible for overall project management, propulsion system integration, development of subsystem and system technologies that are cross-cutting for airbreathing and advanced rocket concepts.
- **Langley Research Center (LaRC)**
  - Langley is responsible for aerodynamics and aerothermodynamics design and integration of airframe and dual mode scramjet (ramjet and scramjet) airbreathing propulsion systems.
- **Stennis Space Center (SSC)**
  - Stennis is responsible for rocket propulsion system and subsystem testing.
- **Glenn Research Center (GRC)**
  - Glenn is responsible for both rocket-based and turbine based combined cycle flowpath definition. Primary focus will be on the combustion and internal flow physics of multimode air breathing propulsion systems. Foundation propulsion technologies (e.g., analytical tools, propellant research and high temperature propulsion materials) will also be conducted .
- **Kennedy Space Center (KSC)**
  - Kennedy is responsible for ground operations technologies.
- **Dryden Flight Research Center (DFRC)**
  - Dryden is responsible for flight testing and operations.

Propulsion Technology & Integration Project

- **System Design & Integration/Cross-cutting Technologies (MSFC Lead)**
  - **Assure an integrated systems approach to propulsion technology development**
  - **Develop subsystem and system cross-cutting technologies for air breathing and advanced rocket concepts.**
    - Ancillary subsystem technologies (e.g., turbopumps, valves, controllers, actuators, etc.) and system analytical models

- **Aerodynamic/Aerothermodynamic/Dual Mode Scramjet (LaRC Lead)**
  - **Focused on aerodynamic and aerothermodynamic design and integration of airframe and dual mode (ramjet/scramjet) air breathing propulsion systems.**
  - **Integrated with the X-43 (Hyper X) project Base R&T Program and the Propulsion Research and Technology Project.**
  - **Current tasks include concept assessments to support an air breathing propulsion flight demonstrator.**

- **Advanced Rocket Technologies (MSFC Lead)**
  - **Focus on advanced rocket cycles and concepts, including pulse detonation rocket engines (PDRE) and other advanced engine concepts.**

Propulsion Research & Technology Project

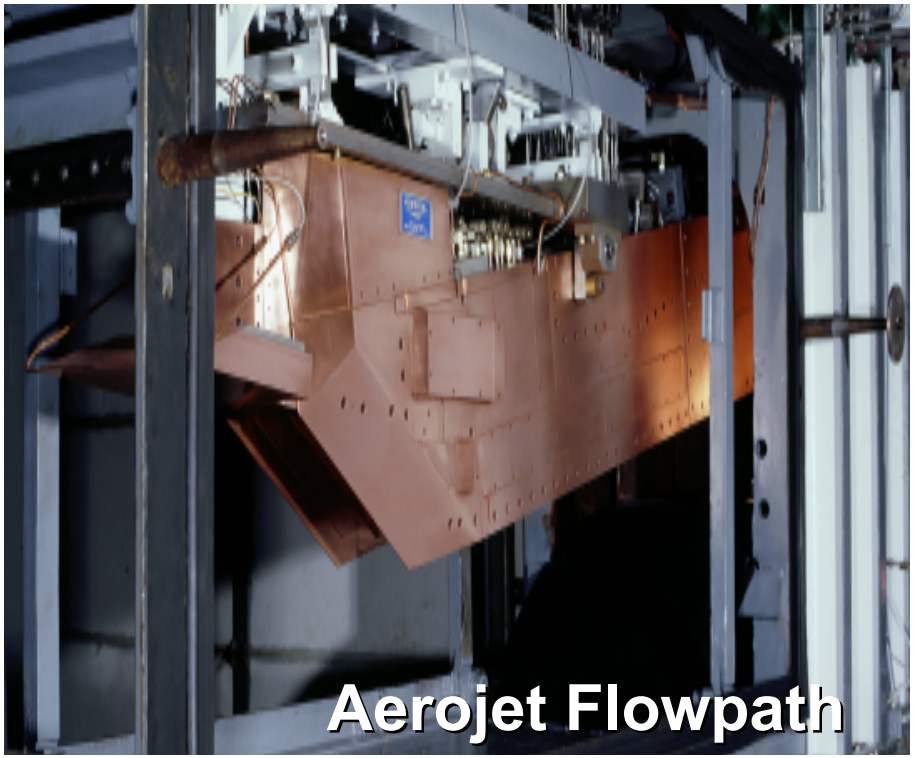
- **Combined Cycle Flowpath Performance (GRC Lead)**
  - Prime focus on R&T development, flowpath definition, and flowpath performance of multi-mode air breathing propulsion systems.
  - Current tasks include wind tunnel testing of multiple industry and in-house rocket based combined cycle (RBCC) flowpath concepts.
  - Responsible for turbine concepts and technology that support turbine based combined cycle (TBCC) and combination propulsion flowpaths that utilize turbine based systems.

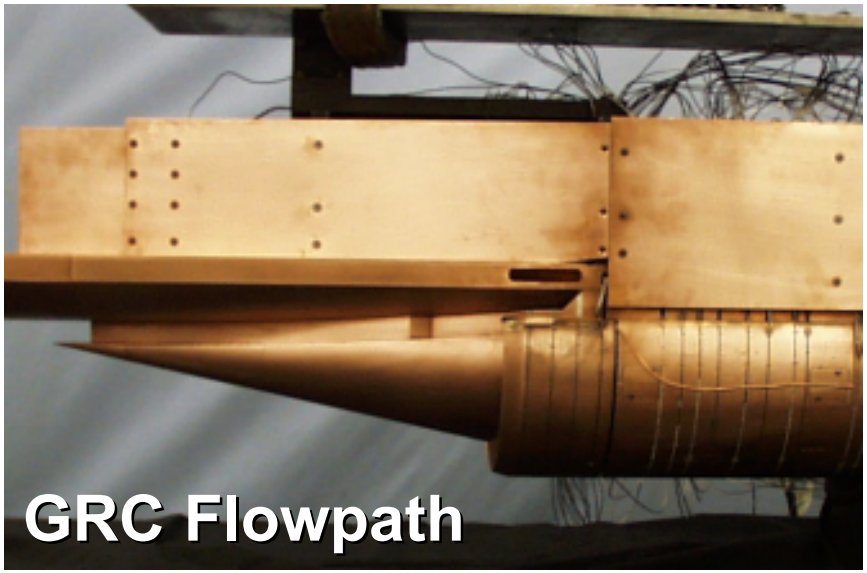
- **Foundation Propulsion Technology (GRC Lead)**
  - Foundational research and technology development in analytical tools, high temperature propulsion materials research, and propellant research.
  - Focused on low TRL activities required to maintain a robust, long term propulsion technology program.

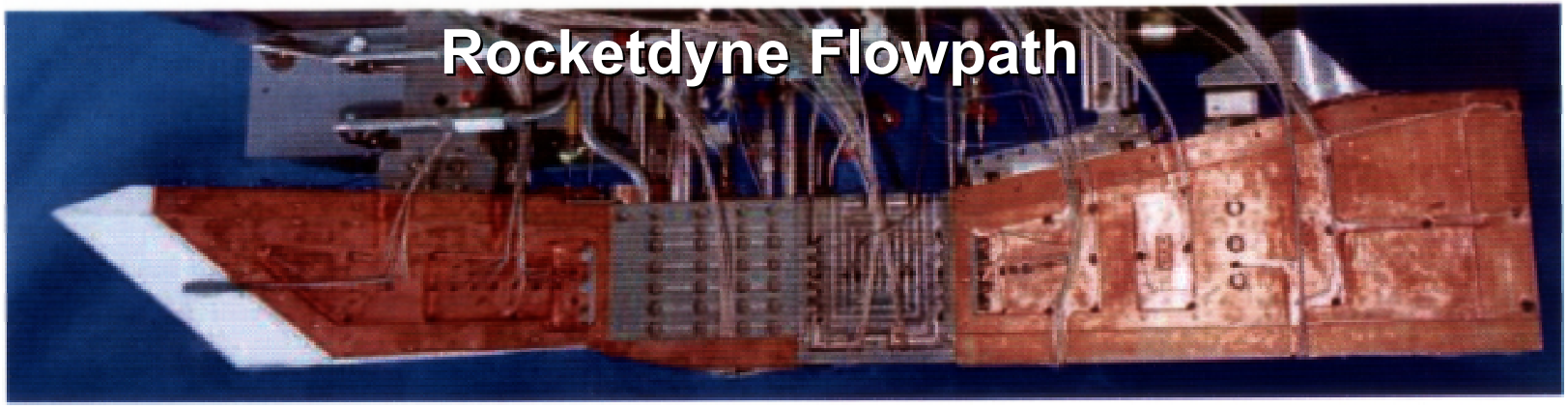
Accomplishments

- **Aerojet & Rocketdyne Flowpath Tested**
  - Test Conducted From M 0 to Mach 8
  - Total Of 253 Test Conducted
  - Good Overall Performance
- **Several First In Testing**
  - Dynamic Trajectory Simulation (AAR -> RAM and RAM-> SCRAM))
  - SCRAM Testing @ High Dynamic Pressure (M8 @ 1,200 Psf)
- **Parametric Test Performed By Pennsylvania State University**
- **Trailblazer Concept Development**
  - Lead By Glenn Research Center
  - Currently Testing @ GASL
- **System Studies**
  - Various Vehicle/Engine Combinations Being Studied
    - RBCC
    - TBCC
    - PDE
  - Sensitivity Trades Being Made
    - Trajectories
    - Fineness ratio
    - Payload capability

RBCC Flowpath Test Hardware







Accomplishments (Cont'd)

Operating Mode	Aerojet		Rocketdyne	
	No. Of Runs	Test Time (Sec)	No. Of Runs	Test Time (Sec)
Sea-Level Static	31	173	34	342
Air-Augmented Rocket	12	97	15	288
AAR/RAM Transition	12	97	32	465
- AAR/RAM Traj Sim.	**0**	**0**	**11**	**140**
RAM	28 (14*)	342 (246*)	21	325
RAM/SCRAM Transition	0	0	2	50
SCRAM	8*	112*	58	1218
SCRAM/Rocket Transition	21*	279*	0	0
Rocket-Only	16	129	10	72

*** Direct-Connect Tests**

Base Propulsion Roadmap

Propulsion Technology Project — 2000 PMC

Major Milestones ▲
Commit to flight configuration Decisions ◆

2000	2001	2002	2003	2004	2005
X-43 Flight▲	▲	▲ ◆ 1st Eng Sel		◆ 2nd Eng Sel	1st A/B Prop. Flt. Demo ▲

Key Tasks

Flight Demostrator

◆ Submit Pathfinder Proposal

◆ Submit Pathfinder Proposal

Propulsion Technology & Integration

- System Design & Integration/Cross-cutting Technologies
- Aerodynamic/Aerothermo-dynamic/Dual Mode Scramjet
- Advanced Rocket Technologies

System Analysis Technology Evaluation

System Design & Integration

Subsystem Technologies (turbopumps,valves, controllers, actuators, etc.)

Dual mode Scramjet (X-34 Flights), 1st Prop. Flight Demo

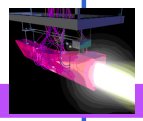
High T/W, Long-life Testbed (2nd Generation) (3rd Generation)

Williams Engine

PDE Rocket

Propulsion Research & Technology

- Combined Cycle Flowpath Performance



Combined Cycle Flowpath Design/Performance

TBCC

- Foundation Propulsion Technologies

Propulsion Materials and Structures

Safe Life Design

Advanced Propellants

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Milestone Status

First Flight Test of X-43

G

- Planned Completion Date: 3rd Qtr / FY00
- Output: Scramjet/Vehicle Performance for M-7 Conditions
- Outcome: Test Results From Mach 7 Flight Test
- Status: On Schedule

Complete 1st Demo Vehicle Preliminary Design

G

- Planned Completion Date: 1st Qtr / FY01
- Output: FY05 Flight Demo Vehicle Preliminary Design
- Outcome: Selection Of FY05 Demo Vehicle Approach
- Status: Just Initiated

Second Flight Test of X-43

G

- Planned Completion Date: 1st Qtr / FY01
- Output: Scramjet/Vehicle Performance for M-7 Conditions
- Outcome: Test Results From Mach 7 Flight Test
- Status: On Schedule

Milestone Status (Cont'd)

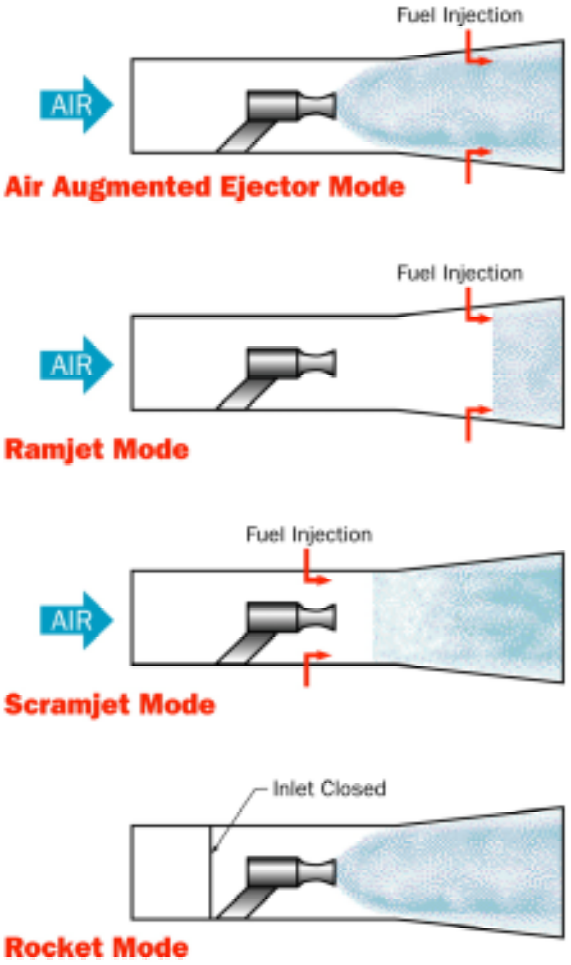
- **Third Flight Test of X-43** — G
  - Planned Completion Date: 4th Qtr / FY01
  - Output: Scramjet/Vehicle Performance for M-10 Conditions
  - Outcome: Test Results From Mach 10 Flight Test
  - Status: On Schedule

- **1st Demo Flowpath Definition & Testing Completed** — G
  - Planned Completion Date: 4th Qtr / FY01
  - Output: Complete Boilerplate Flowpath Ground Testing
  - Outcome: Flowpath Performance of Aerojet & Rocketdyne Flowpaths
  - Status: Just Initiated

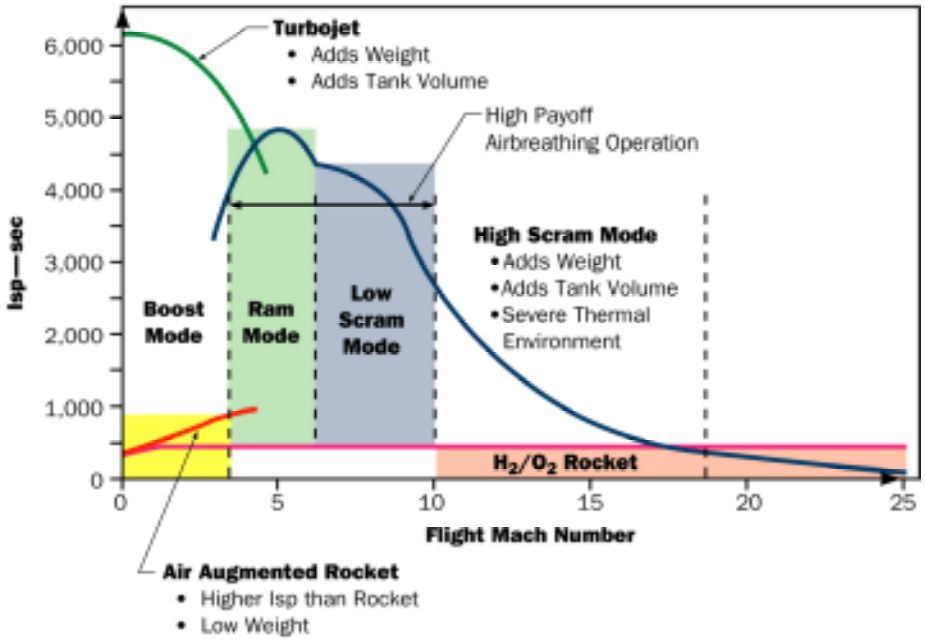
- **1st Demo Air Breathing Engine Selection** — G
  - Planned Completion Date: 4th Qtr / FY01
  - Output: Preliminary Design of Flight Demo Engine System
  - Outcome: Engine Design Selection For FY05 Flight Demo
  - Status: Just Initiated

Simplified Schematic Of RBCC Operating Modes & Performance Benefits

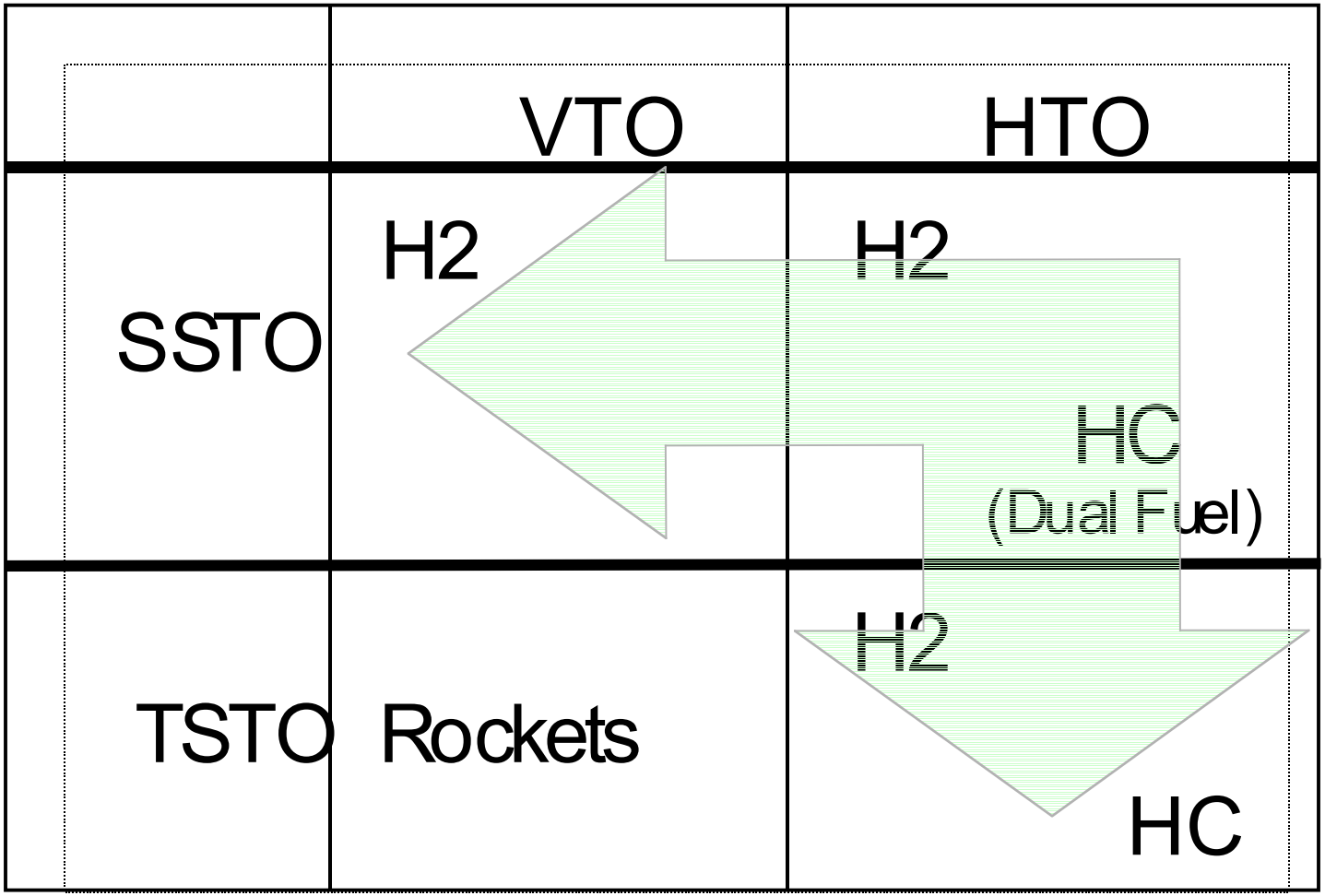
RBCC Operating Modes



Increased Mission Isp



Integrated Airbreathing Propulsion Plan



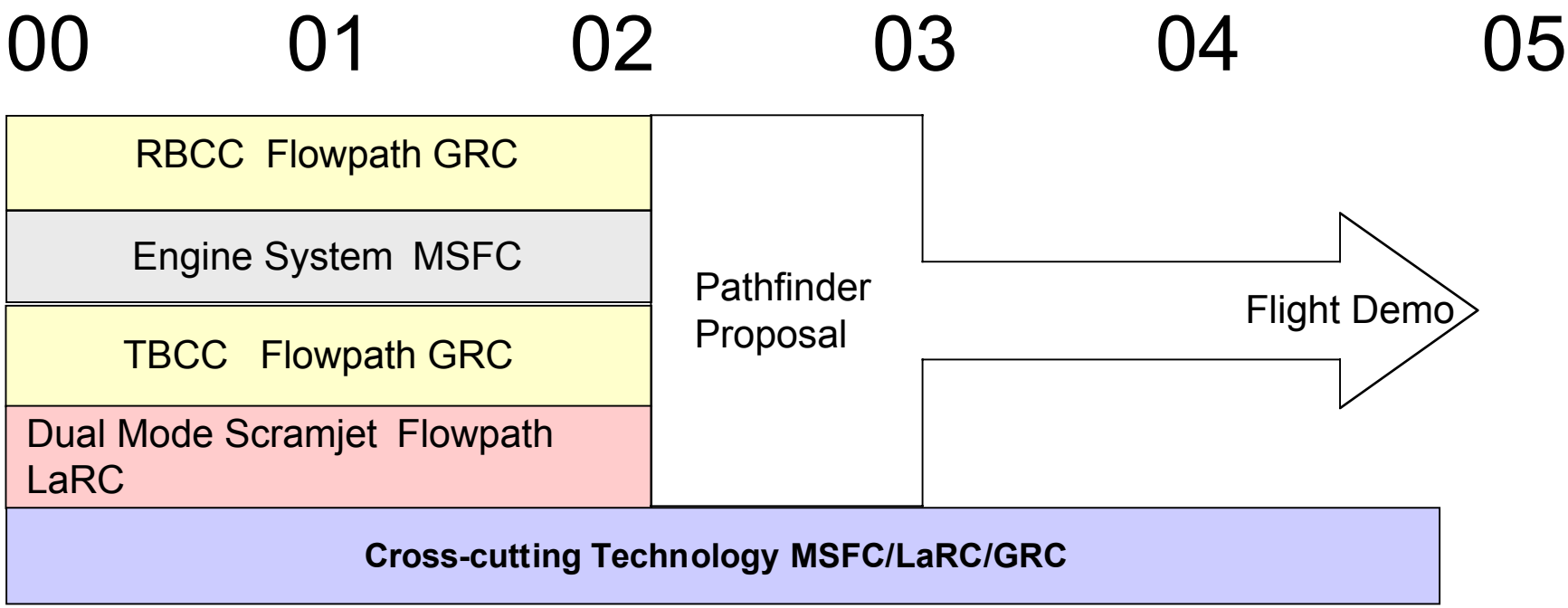
Integrated Airbreathing Propulsion Plan

Vertical SSTO		Horizontal SSTO
High T Rocket	*Low Speed*	High T Turbo
Low Speed (One Duct)	*Mode Trans*	High Speed (Two Ducts)
Mach 10/11	*High Speed*	Mach 15+
Lower I * Higher T/W	*T/W*	Higher I* Lower T/W
Lower L/D Less Capture	*Vehicle Integration*	Higher L/D More Capture
H2	*Fuel*	H2 or Dual Fuel

Cross-cutting Technologies

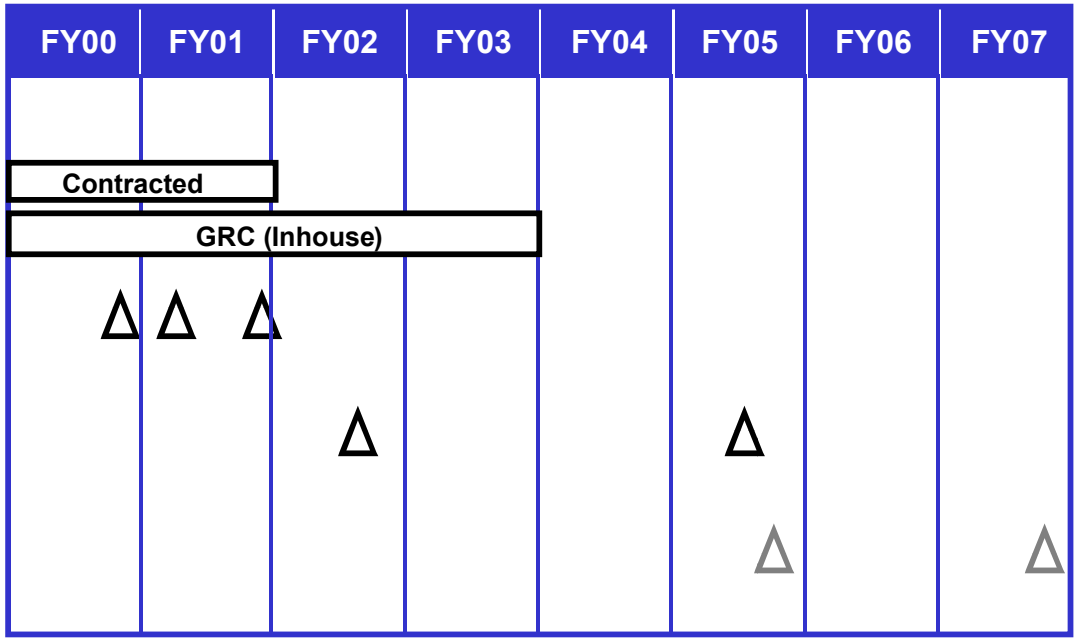
Advanced Materials	Robust Rockets
Systems Analysis	Health Management
Engine Systems	DesignMethods
Turbopumps	Engine Controls

Integrated Airbreathing Propulsion Plan

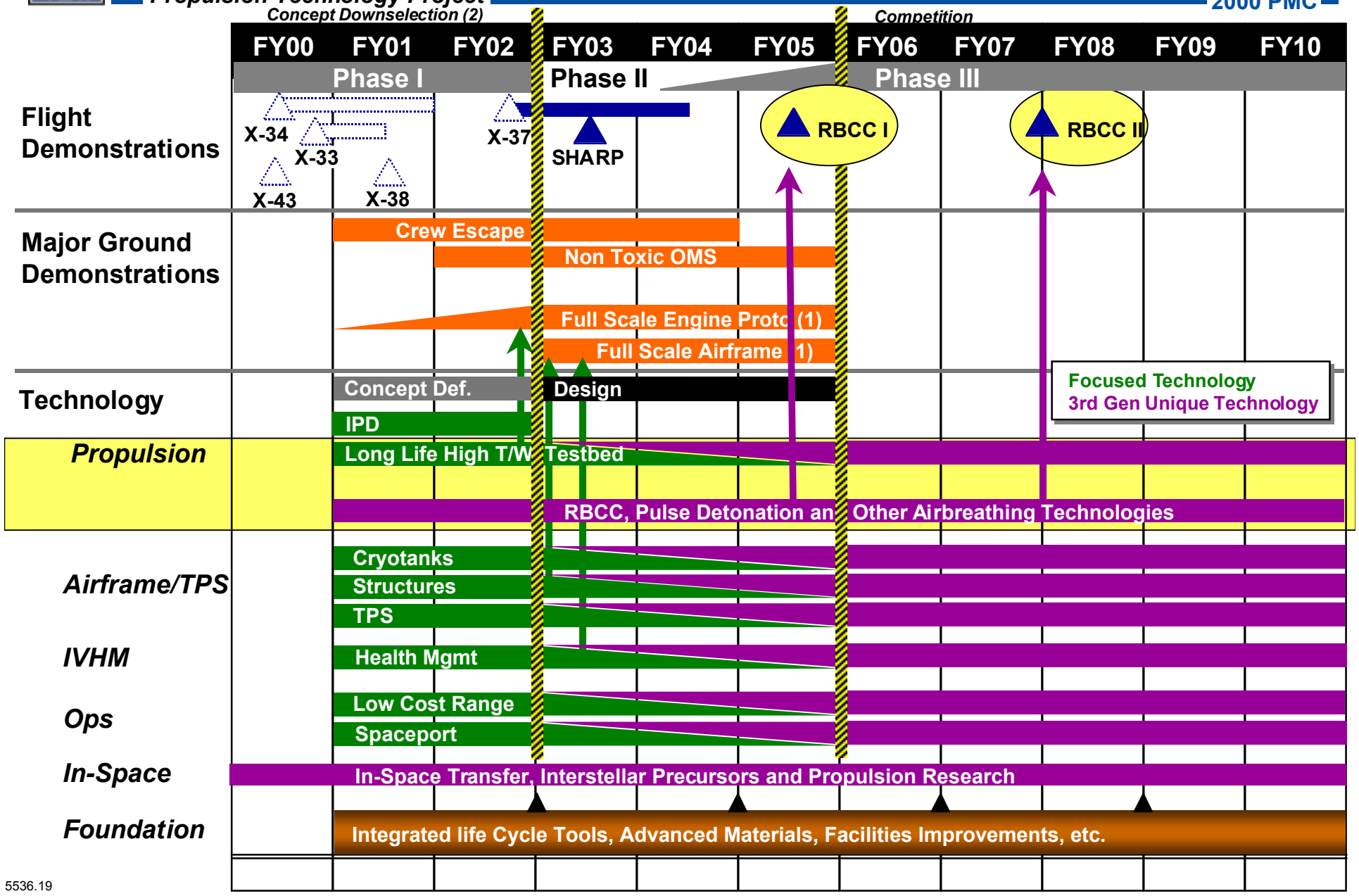


Schedule Summary

- Flowpath Testing Completed
- X-43 Flights
- Pathfinder Proposal Submission
- Flight Demonstrators



2001 – 2010 Roadmap



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